ARMY RESEARCH LABORATORY

A Hitch Angle Measurement Device

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Abstract

As part of a project to demonstrate that an unmanned ground vehicle (UGV) could remotely back up with a trailer, a simple proof-of-concept device was designed to measure the angle between a high-mobility multipurpose wheeled vehicle (HMMWV) pintle hook and a trailer tow bar. A suitable algorithm could compute the UGV steering angle required for a trailer to follow a given reverse path and would be a function of the angle between the UGV and the trailer. This report gives the details of a design for a hitch angle measurement device (HAMD) to be used as input to a steering transfer function. Derivation of the transfer function is not included.

Table of Contents

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List of Figures

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List of Tables

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1. Introduction

The U.S. Army Research Laboratory (ARL) has helped develop a small fleet of teleoperated high-mobility multipurpose wheeled vehicles (HMMWV) (Figure 1) for use in battlefield environments in which it may be too hazardous for a soldier to operate.[1] This example of an unmanned ground vehicle (UGV) is remotely controlled by an operator but has a certain degree of robotic autonomy. There are many potential missions to be performed by robotic vehicles. These include but are not limited to:

- reconnaissance,
- remote sentry,
- telepresence,
- smoke generation,
- mine detection/countermine,
- mine deployment/recovery,
- target acquisition,
- target designation,
- battle damage assessment,
- nuclear, biological, and chemical detection,
- meteorological assessment,
- electronic warfare, and
- weapon platform (e.g., recoilless rifle, smart mortar).

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[1] Haas, G. A., P. David, and B. T. Haug. "Target Acquisition and Engagement From an Unmanned Ground Vehicle: The Robotics Test Bed of DEMO 1." ARL-TR-1063, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, 1996.

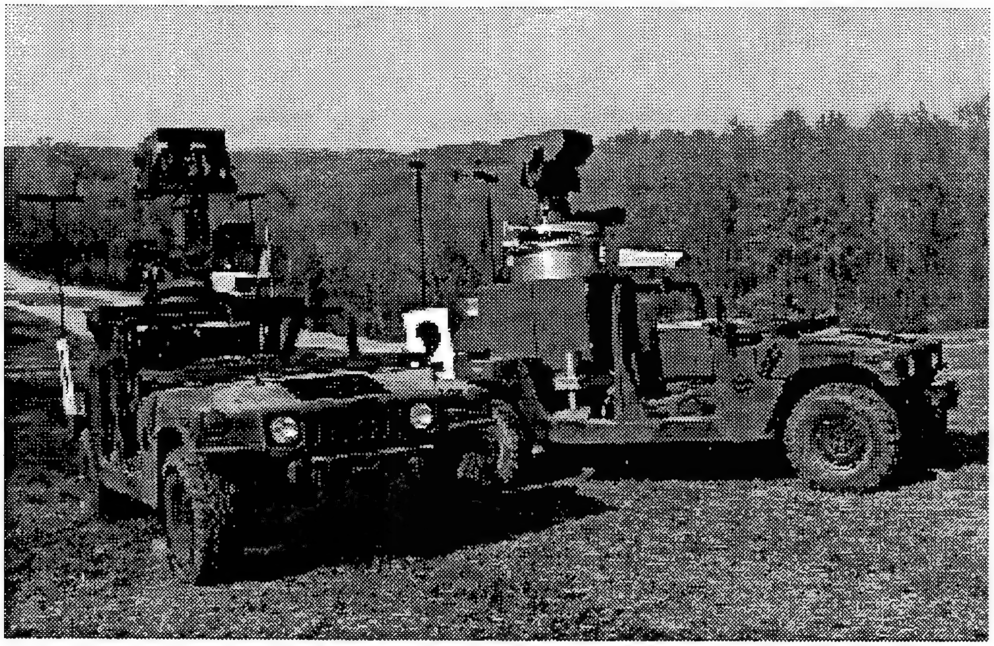

Figure 1. Teleoperated HMMWVs.

Rather than design different robotic vehicles for each mission, a UGV could serve as a multiuse carrier of modular mission packages. This approach would eliminate parallel expenditures on robotic vehicle development and would allow a user to direct limited resources toward mission function. Many of these mission packages could reside on a deployable UGV-towable trailer that could be dropped off and picked up by a UGV. This would provide greater mission flexibility by freeing expensive robotic mobility resources for other missions. A trailer-mounted weapon platform would protect a UGV from exposure to weapon launch shocks and overpressures.

A disadvantage of an UGV-towable trailer is the requirement for remote decoupling and recoupling of the trailer. In addition to a mechanical coupling between the UGV and trailer, there would also be a need for a power and, possibly, a data link coupler/decoupler.

The greatest difficulty in remotely operating a UGV with a trailer would, at first glance, seem to be backing up with the trailer. Moving in reverse with a trailer can be a tricky operation, as anyone

who has ever backed up a car with a boat trailer can attest. One might think that the difficulty of the task would be compounded if done remotely, but that may not be the case. If a suitable algorithm could compute the UGV steering angle required for a trailer to follow a given reverse path, then the task of remote backing could be made as easy as remotely driving forward. The remote operator would simply be provided with a trailer's-eye view and steer the trailer as one would steer the UGV. Such a steering transfer function would be a function of the angle between the UGV and the trailer.[2]

As part of a project to demonstrate that a UGV could remotely back up with a trailer, a device was designed to measure the angle between a HMMWV pintle hook and a trailer tow bar. This report gives the details of a design for a hitch angle measurement device (HAMD) to be used as input to a steering transfer function. Derivation of the transfer function is not included.

2. HAMD

The HAMD (shown in Figure 2) is mounted on the HMMWV beam to which the tailgate is fastened (the "D" beam). The unit is housed in a cover to protect the internal components from mud, rain, etc. (cover removed in figure for clarity). This simple proof-of-concept device was easily and inexpensively made utilizing off-the-shelf components and a minimum of machining. A bill of materials and component drawings can be found in Appendix A.

An exploded view of the HAMD is shown in Figure 3. The angle measurement rod pivots on a hinge assembly comprised of a shaft held by ball bearings. The shaft is connected to a rotary variable inductance transducer (RVIT) via a bellows coupling and a transducer gear head (Figure 4). Specifications for the RVIT and gear head are found in Appendices B and C, respectively. The flexible bellows coupling transmits the rotary movement of the shaft to the gear head without torsional error. Small inaccuracies in alignment are taken up by the coupling. The gear head attaches to the RVIT and reduces the rotary movement by a factor of 3 to 1. A 360° motion of the gear head

[2] Larsson, U., C. Zell, K. Hyyppa, and A. Wernersson. "Navigating an Articulated Vehicle and Reversing With a Trailer." *1994 IEEE International Conference on Robotics and Automation*, San Diego, CA, May 1994.

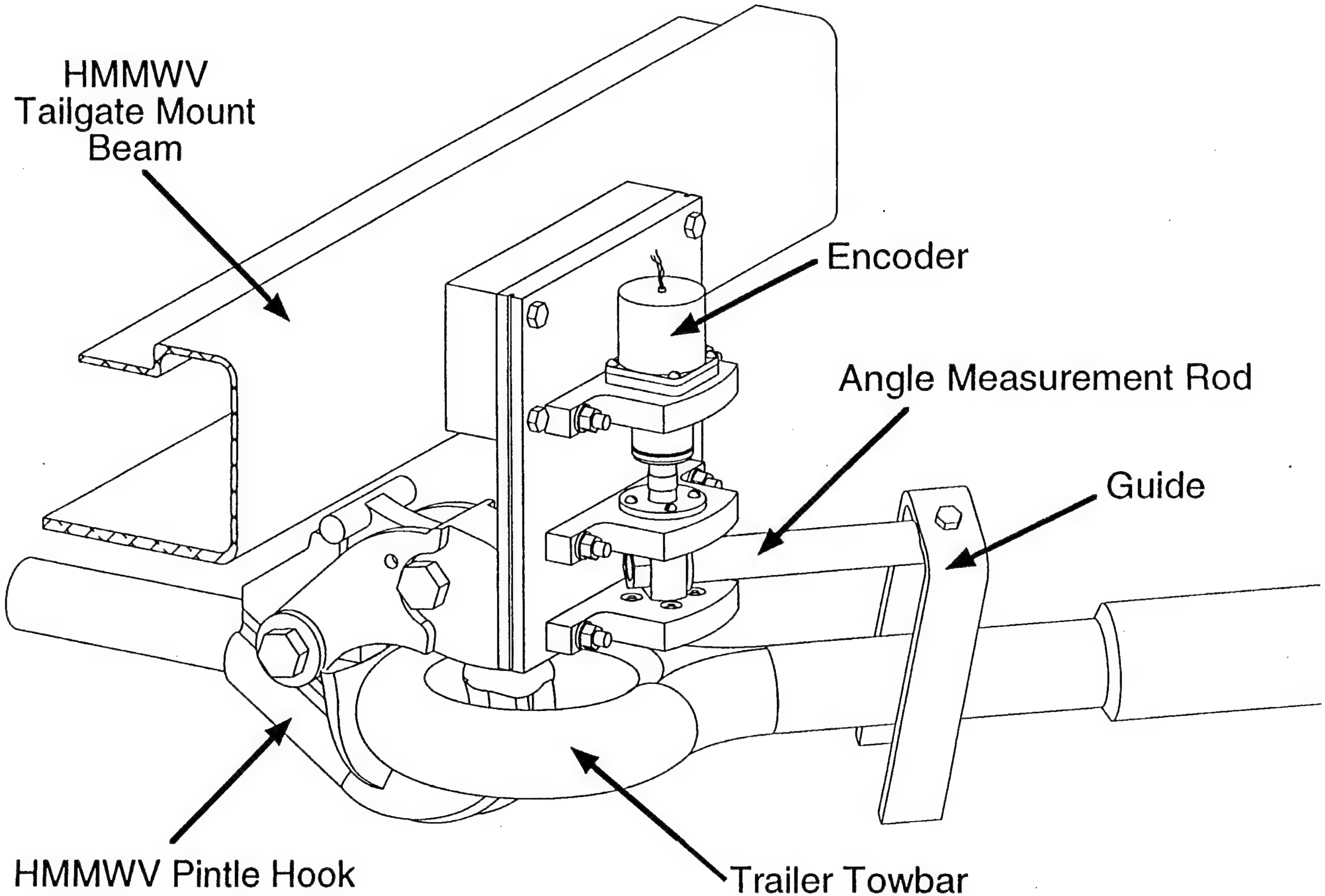

Figure 2. HAMD.

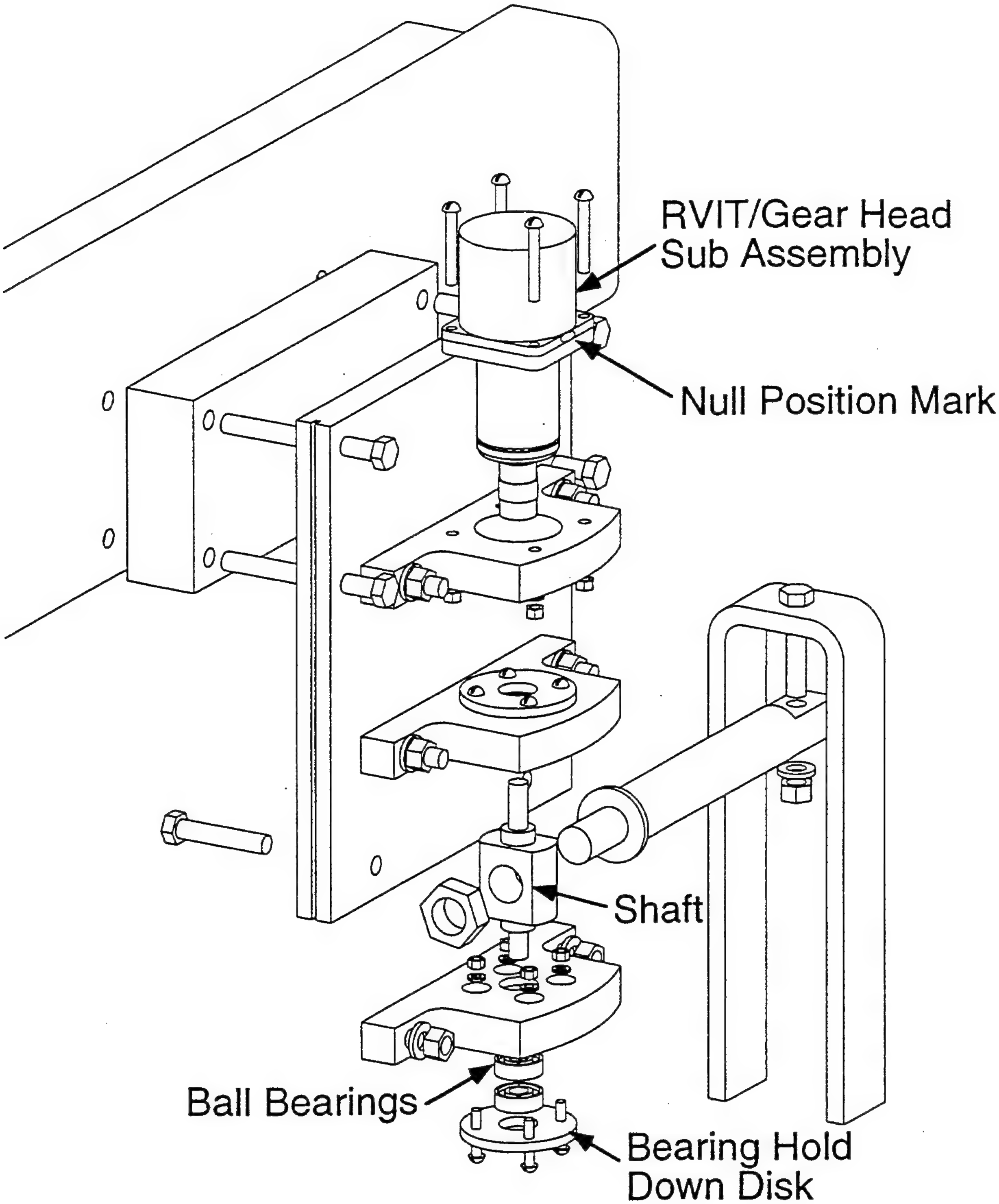

Figure 3. HAMD Exploded View.

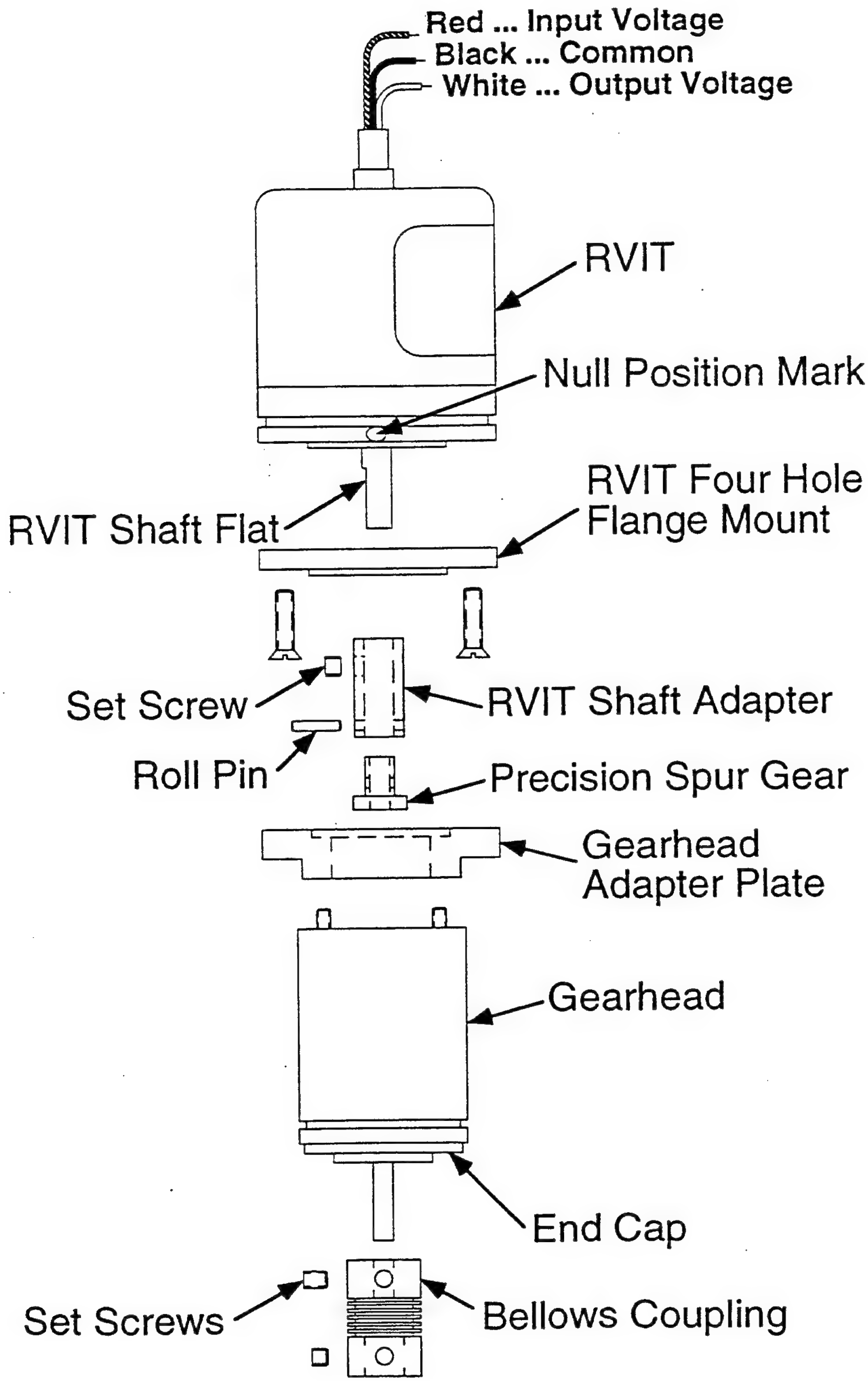

Figure 4. RVIT/Gear Head Subassembly: Exploded View.

shaft maps to a 120° motion of the RVIT shaft, which is the range of the RVIT. The voltage output from the RVIT is proportional to the angle between the trailer and HMMWV.

2.1 HAMD Operation. Figure 5 shows the HAMD in operation. As the trailer tow bar pivots about the HMMWV pintle hook, it contacts a two-pronged guide that straddles the shaft of the tow bar and is attached to the end of the angle measurement rod. The tow bar and the angle rod pivot about different axes because the HAMD is mounted aft of the pintle hook and because the tow bar's pivot axis is not constant due to movement between the eye of the tow bar and the pintle hook. For this reason, as the tow bar moves, the guide is free to rotate about the centerline of the angle rod and slide along the shaft of the tow bar. The prongs of the guide remain perpendicular to the centerline of the tow bar. In this manner, the centerlines of the angle rod and tow bar remain parallel and the guide moves the angle rod through the same angle as the tow bar. Because the tow bar can move up and down, forward and back, and roll between the guide, neither the towing load nor the loads due to the bouncing of the trailer are transmitted to the HAMD.

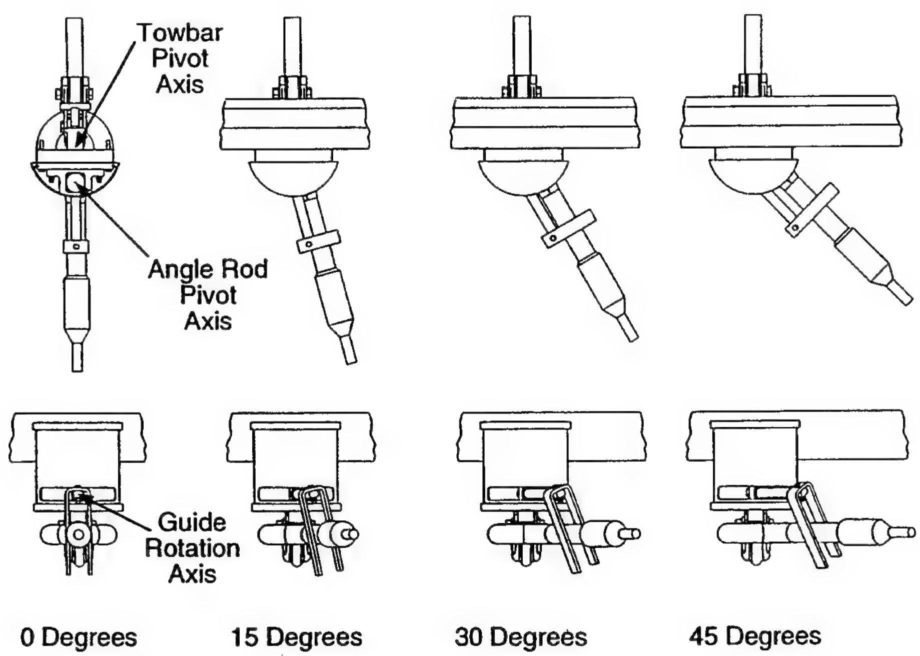

Figure 5. HAMD: Operation.

2.2 HAMD Assembly Instructions. The HAMD is designed for easy assembly. Most parts simply bolt together using 1/4-20 UNC bolts and nuts with lock washers. The following are steps to assemble the shaft subassembly (refer to Figure 3 and the drawings in Appendix A).

(1) Place the ball bearings in the pivot mount plates.

(2) Secure the bearings with the bearing hold-down disks.

(3) Bolt the bottom pivot mount plate to the D-beam mount plate.

(4) Put the short end of the shaft into the bottom bearings subassembly.

(5) Slide the top bearing subassembly onto the long end of the shaft.

(6) Ensure that the shaft rotates freely.

(7) Bolt the top pivot mount plate to the D-beam mount plate.

The RVIT has a null position that is indicated by a white dot on the RVIT's housing. When the flat on the RVIT shaft is aligned with the null mark, the output from the RVIT is 0 V. A clockwise shaft rotation (looking down the shaft at the RVIT) increases the output voltage. The RVIT should be mounted with the null mark facing the trailer. Thus, when the rear of the trailer swings toward the passenger side of the HMMWV, the RVIT will output a positive voltage. Likewise, when the rear of the trailer swings toward the driver's side of the HMMWV, the RVIT will output a negative voltage.

The gear head is a zero-backlash 3:1 ratio reducer. Backlash is a measure of how well mating gears fit together. Care must be taken to properly engage the precision spur gear on the RVIT shaft to the gear head. The following are steps to assemble the RVIT/gear head subassembly (refer to Figures 3 and 4 and Appendices A, B, and C).

(1) Bolt the RVIT mount plate to the D-beam mount plate.

(2) Attach the four-hole flange mount to the RVIT.

(3) Secure the precision spur gear to the RVIT shaft adapter with a roll pin.

(4) Attach the gear subassembly to the shaft of the RVIT. Tighten the set screw on the flat portion of the shaft.

(5) Remove the end cap from the shaft end of the gear head by removing two screws and then pulling the cap off using the tool shown in Appendix C.

(6) Attach the gear head adapter plate with the two screws sticking out from the gear head.

(7) Beneath the end cap of the gear head, find the only slotted shaft. Holding the input shaft and the housing of the gear head, turn the slotted shaft with a screwdriver counterclockwise approximately 30°.

(8) Gently place the gear head onto the RVIT and slightly turn the screwdriver back and forth until the spur gear is engaged with the gear head.

(9) Release the shaft and housing of the gear head. Be sure to hold the RVIT and gear head together through the remaining steps.

(10) Replace the end cap of the gear head.

(11) Slip the bellows coupling onto the shaft of the gear head. Tighten the set screws.

(12) With the white null position mark pointing outward, attach the RVIT/gear head subassembly to the RVIT mount plate with four screws and nuts, slipping the bellows coupling onto the shaft of the hinge assembly.

(13) Connect the RVIT to a power supply and voltmeter.

(14) Rotate the shaft of the hinge assembly so that the flat faces are parallel with the D-beam mount plate.

(15) Holding the shaft, rotate the bellows coupling until the output of the RVIT is 0 V.

(16) Tighten the bellows coupling set screws on the pivot shaft.

The following are steps to attach the HAMD to a HMMWV.

(1) Drill four holes in the HMMWV D-beam centered about the pintle hook using the D-beam mount plate spacer as a guide. The lower two holes should be about 19 mm (0.75 in) from the bottom of the D-beam.

(2) Bolt the HAMD to the D-beam.

(3) Place the large washer onto the threaded end of the angle measurement bar and put the angle bar into the hole in the shaft.

(4) Tighten the large nut onto the angle bar. Tighten the set screw in the nut.

(5) Connect the trailer tow bar to the HMMWV pintle hook.

(6) Straddle the shaft of the tow bar with the prongs of the guide and the bolt the guide onto the end of the angle measurement bar.

The following are steps to place the sheet metal housing onto the HAMD.

(1) Remove the guide and angle measurement bar.

(2) Slide the sheet metal housing into the grooves of the D-beam mount plate and push down onto the HAMD.

(3) Place the large washer onto the angle measurement bar and pass the angle bar through the slot in the housing and into the hole in the shaft.

(4) Tighten the large nut onto the shaft and then tighten the set screw in the nut.

(5) Secure the bottom housing cap with screws.

(6) Pass the RVIT wires through the top housing cap and then secure with screws.

3. Conclusions

During this project, several other concepts for measuring the angle between a HMMWV and trailer were briefly considered. These included other mechanical methods for detecting the motion of the tow bar. There were also two ideas that did not rely on any mechanical connection. One involved a light sensor on the HMMWV that would detect the orientation of an array of light-emitting diodes (LED) on the trailer. The other concept sought to use range sensors from autofocus cameras to measure the distances to the trailer's two corners and compute the trailer angle from this geometry. However, the latter two ideas required more effort developing electronics and software than time or

resources permitted. The other mechanical methods needed sensors that were not on hand. The HAMD presented in this report began with the RVIT and was designed around the physical geometry of the HMMWV and trailer.

Computer-aided design (CAD) and computer-aided modeling (CAM) played an important role in the design of the HAMD. The device was virtually prototyped before a single component was machined. Both two-dimensional (2-D) mechanical drawings and three-dimensional (3-D) solid models were made, and each assisted in the creation of the other. A virtual mechanism model demonstrated the operation of the HAMD before it was ever bolted to a HMMWV. As a result, the HAMD functioned as expected and provided a method of measuring the angle between a HMMWV and a trailer.

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Appendix A:

Bill of Materials and Drawings

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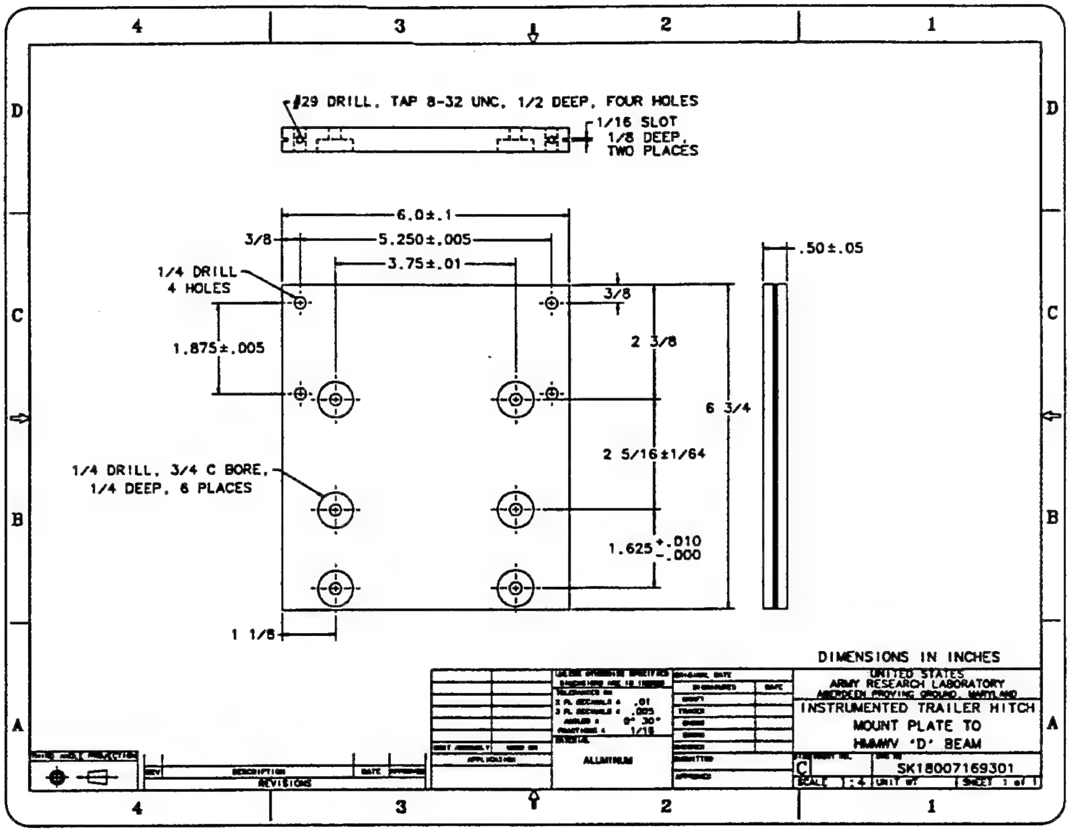
Table A-1. Bill of Materials

<table>
<tr><th colspan="2">Item</th><th>Drawing No.</th><th>Qty.</th></tr>
<tr><td colspan="2">Mount Plate to High-Mobility Multipurpose Wheeled Vehicle (HMMWV)</td><td>SK18007169301</td><td>1</td></tr>
<tr><td colspan="2">Adapter Plate for Gear Head</td><td>SK18007169302</td><td>1</td></tr>
<tr><td colspan="2">Mount Plate for Rotary Variable Inductance Tranducer (RVIT)</td><td>SK18007169303</td><td>1</td></tr>
<tr><td colspan="2">Pivot Mount</td><td>SK18007169304</td><td>2</td></tr>
<tr><td colspan="2">Ball Bearing Hold-Down Disk</td><td>SK18007169305</td><td>2</td></tr>
<tr><td colspan="2">Pivot Shaft for Angle Bar</td><td>SK18007169306</td><td>1</td></tr>
<tr><td colspan="2">Angle Measurement Bar</td><td>SK18007169307</td><td>1</td></tr>
<tr><td colspan="2">Guide for Tow Bar</td><td>SK18007169308</td><td>1</td></tr>
<tr><td colspan="2">Sheet Metal Housing</td><td>SK18007169309</td><td>1</td></tr>
<tr><td colspan="2">Cap for Housing</td><td>SK18007169310</td><td>2</td></tr>
<tr><td colspan="2">Spacer for Mount Plate</td><td>SK18007169311</td><td>1</td></tr>
<tr><td colspan="2">RVIT Shaft Adapter</td><td>SK18007169312</td><td>1</td></tr>
<tr><td colspan="2">Gear Head Face Remover</td><td>SK18007169313</td><td>1</td></tr>
<tr><td colspan="2">RVIT-15-60</td><td>P/N 03180003-000</td><td>1</td></tr>
<tr><td colspan="2">Precision Gear Head (3:1 Ratio)</td><td>Model T642A03S</td><td>1</td></tr>
<tr><td colspan="2">Bellows Coupling</td><td>P/N S9901Z-G404-24</td><td>1</td></tr>
<tr><td rowspan="2">Bearing Hold-Down Disks</td><td colspan="2">5-40 × 5/8-in machine screw, pan-head slotted</td><td>8</td></tr>
<tr><td colspan="2">5-40 machine screw nut and no. 5 split-lock washer</td><td>8 ea.</td></tr>
<tr><td rowspan="2">RVIT and Pivot Mount Plates</td><td colspan="2">1/4-in-20 × 1 1/4-in bolt, hex head</td><td>6</td></tr>
<tr><td colspan="2">1/4-in-20 hex nut and 1/4-in split-lock washer</td><td>6 ea.</td></tr>
<tr><td rowspan="2">RVIT Gear Head Assembly</td><td colspan="2">6-32 × 1-in machine screw, pan- or round-head slotted</td><td>4</td></tr>
<tr><td colspan="2">6-32 machine screw nut and no. 6 split-lock washer</td><td>4 ea.</td></tr>
<tr><td rowspan="2">Mount Plate to HMMWV</td><td colspan="2">1/4-in-20 × 1 1/4-in bolt, hex head</td><td>4</td></tr>
<tr><td colspan="2">1/4-in-20 hex nut and 1/4-in split-lock washer</td><td>4 ea.</td></tr>
<tr><td rowspan="2">Angle Bar to Pivot Shaft</td><td colspan="2">1/2-in-13 hex nut, 5/16-in height</td><td>1</td></tr>
<tr><td colspan="2">1/2-in split-lock washer</td><td>1</td></tr>
</table>

Table A-1. Bill of Materials (continued)

Guide to Angle Bar	1/4-in-20 × 1 1/4-in bolt, hex head	1
	1/4-in-20 hex nut and 1/4-in split-lock washer	1 ea.
Housing Caps	8-32 × 3/8-in machine screw, round-head slotted	4
Gear Head Face Remover	4-40 × 1 1/2-in machine screw, pan-head slotted	4
Angle Measurement Bar	1/2-in-13 hex nut, 5/16-in height and 1/2-in washer	1 ea.



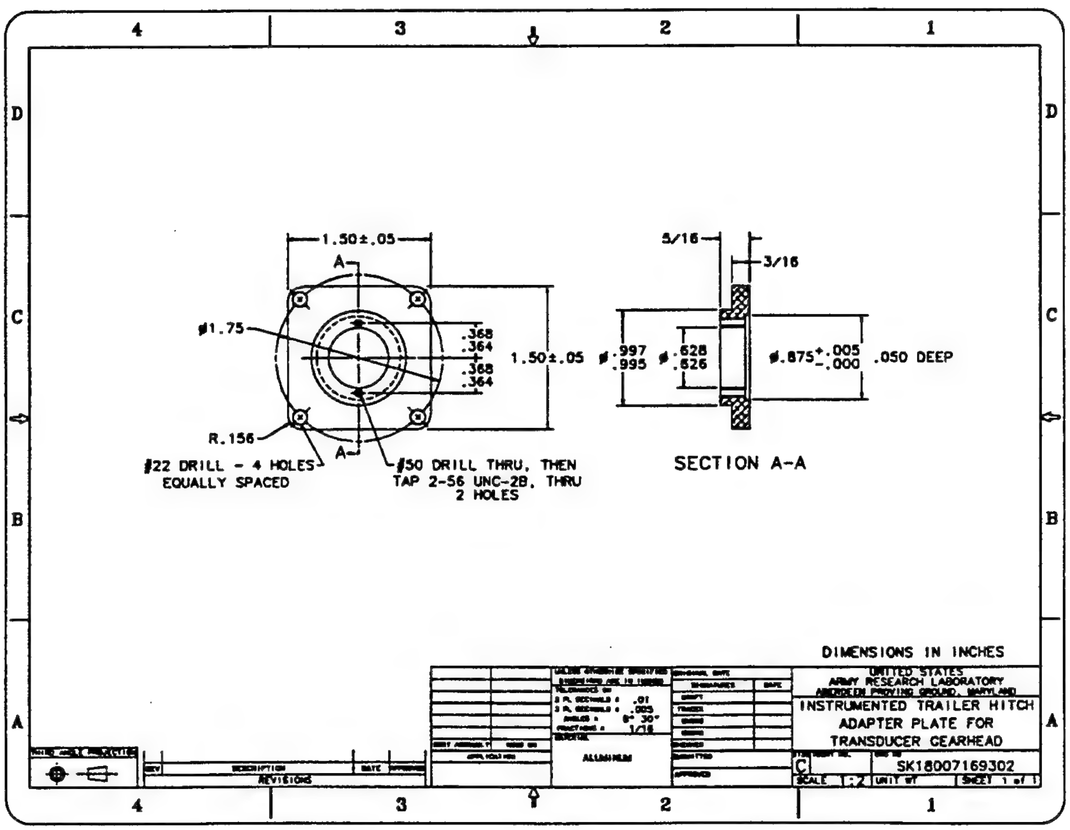
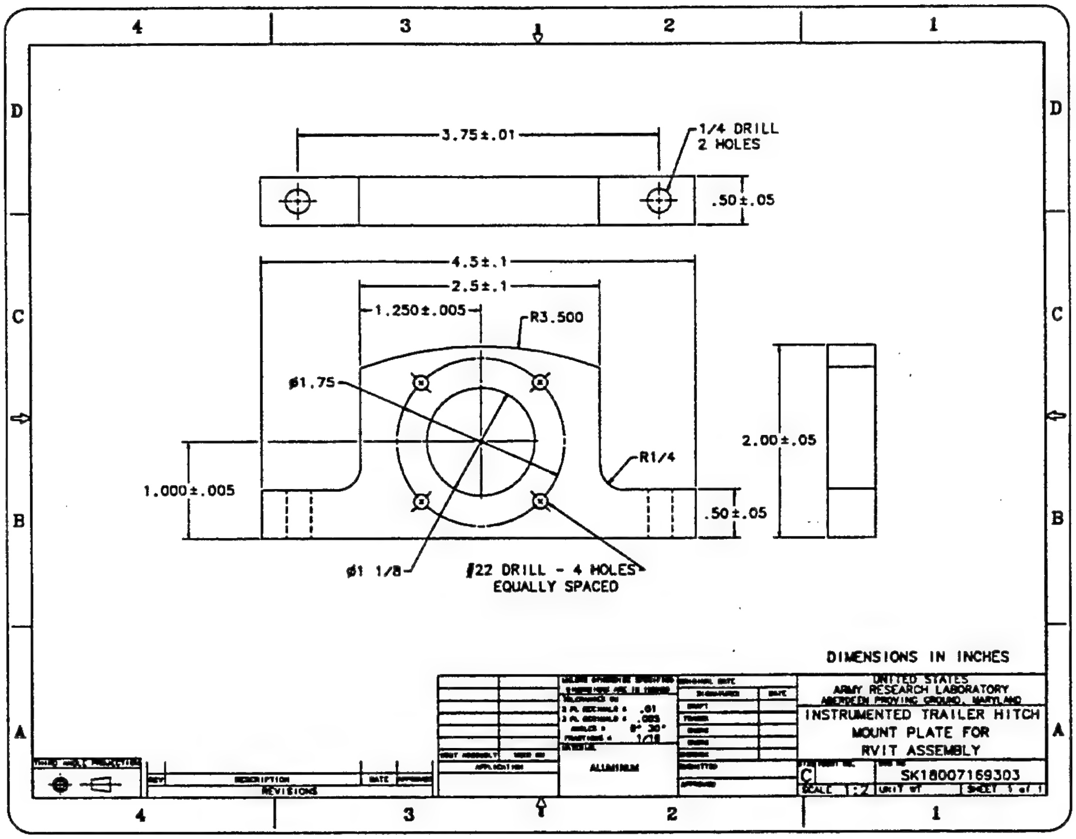


Figure A-1. Beam Mount and Gear Head Adapter Plates.



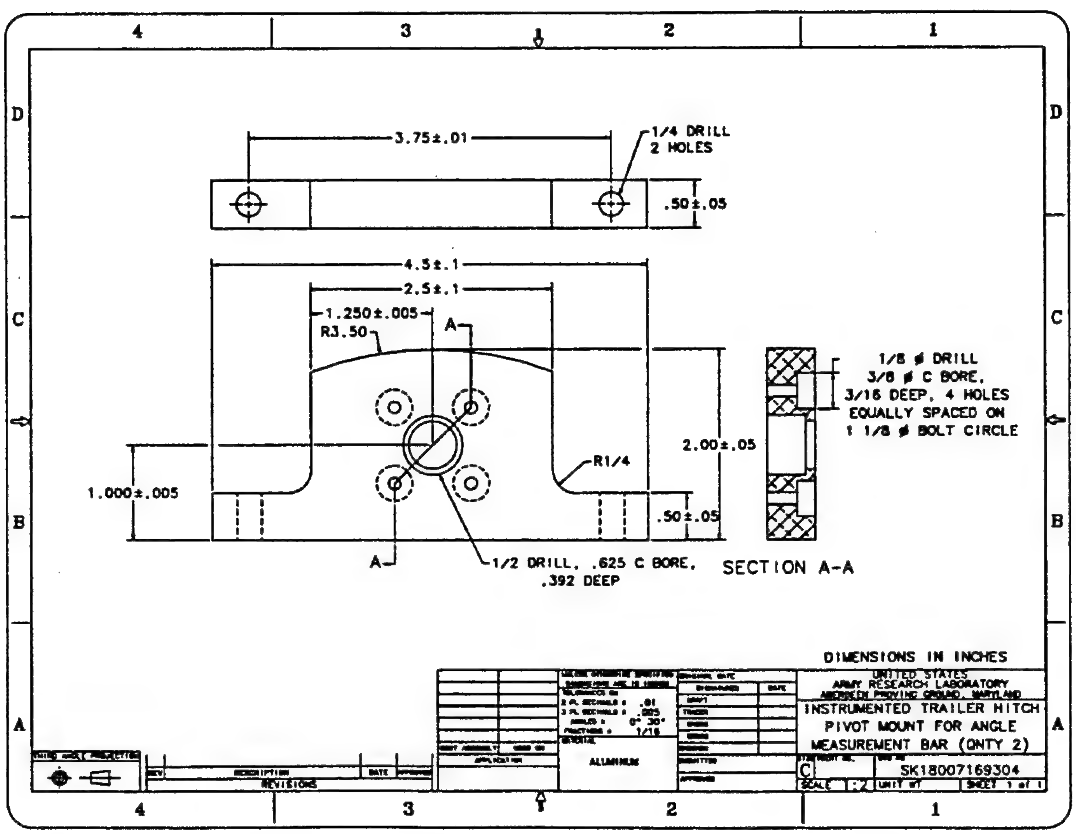
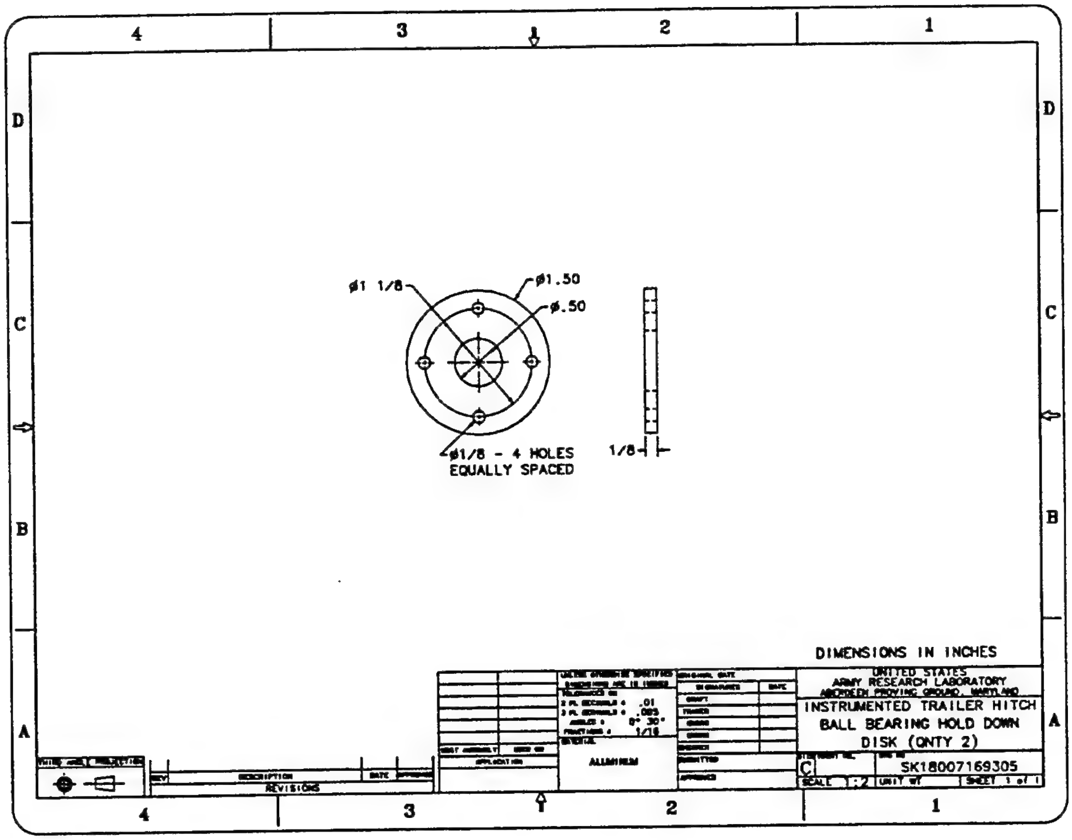


Figure A-2. RVIT Mount and Pivot Mount Plates.



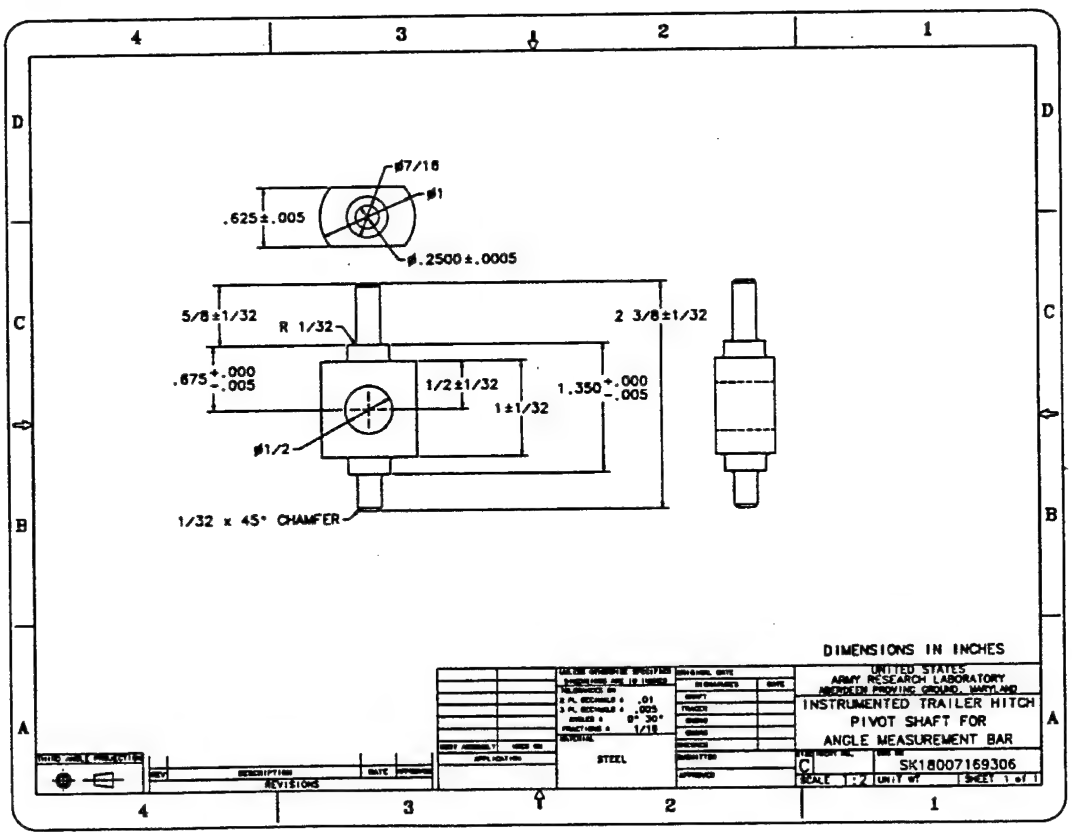
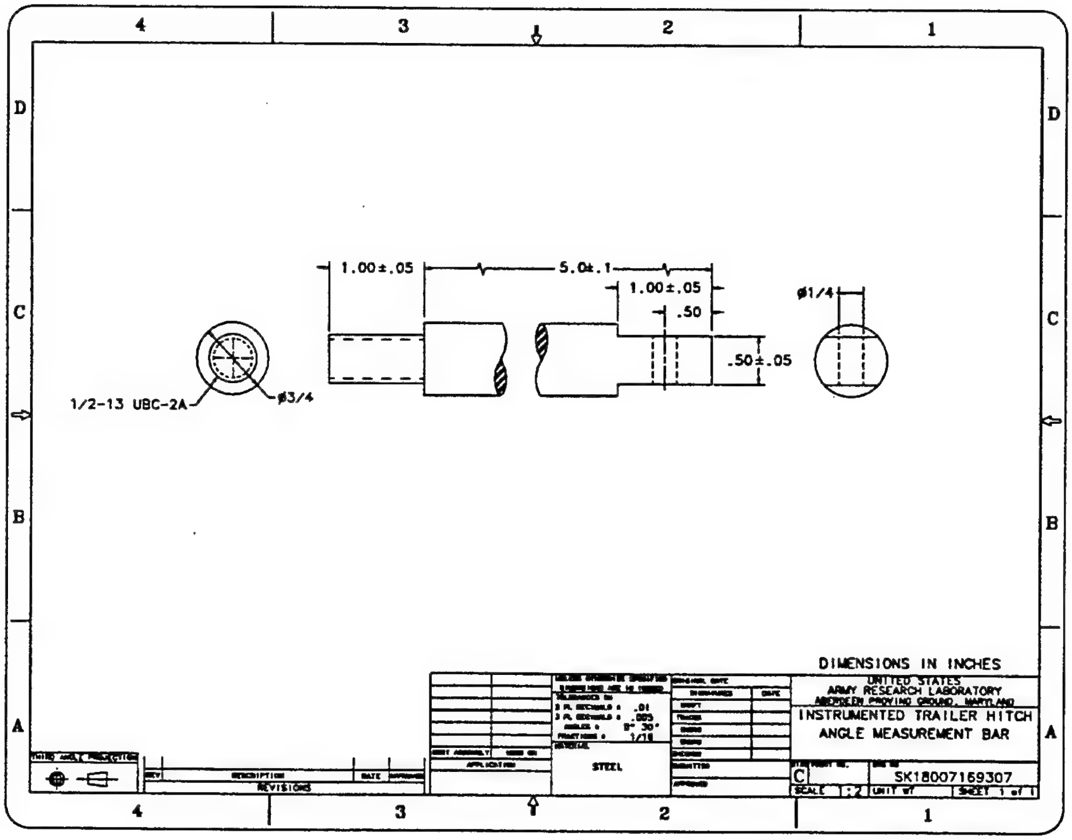


Figure A-3. Bearing Hold-Down and Pivot Shaft.



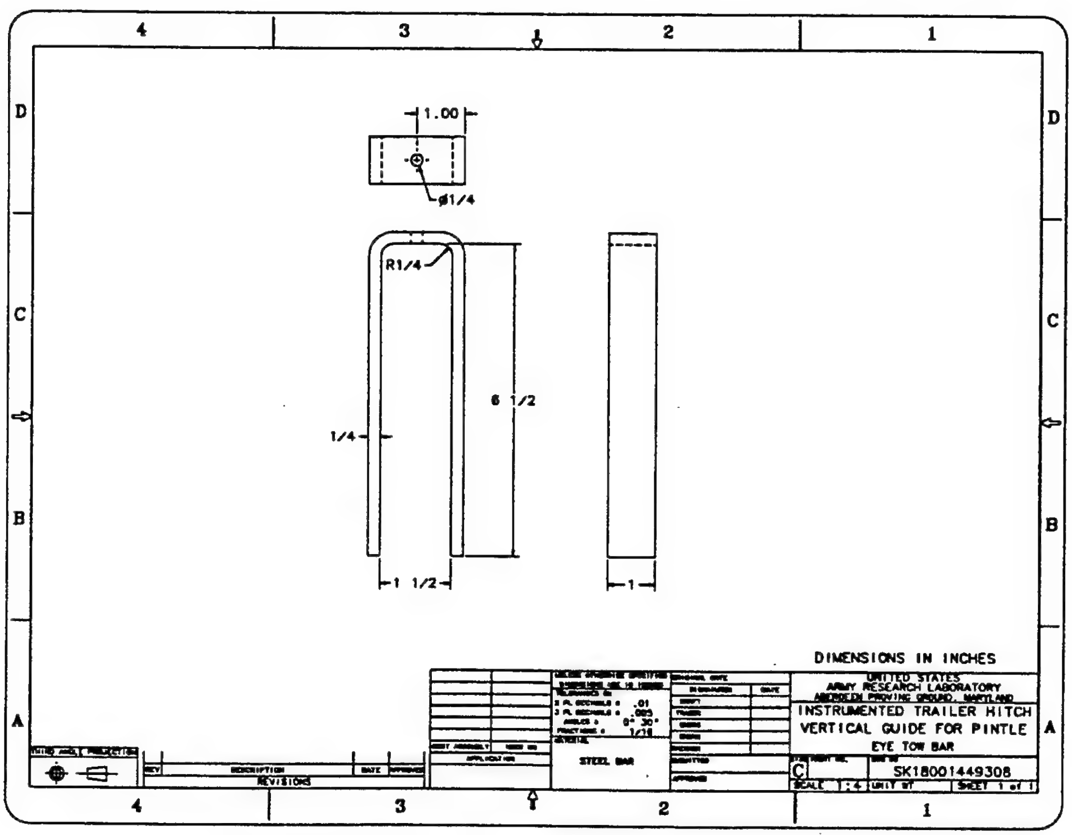
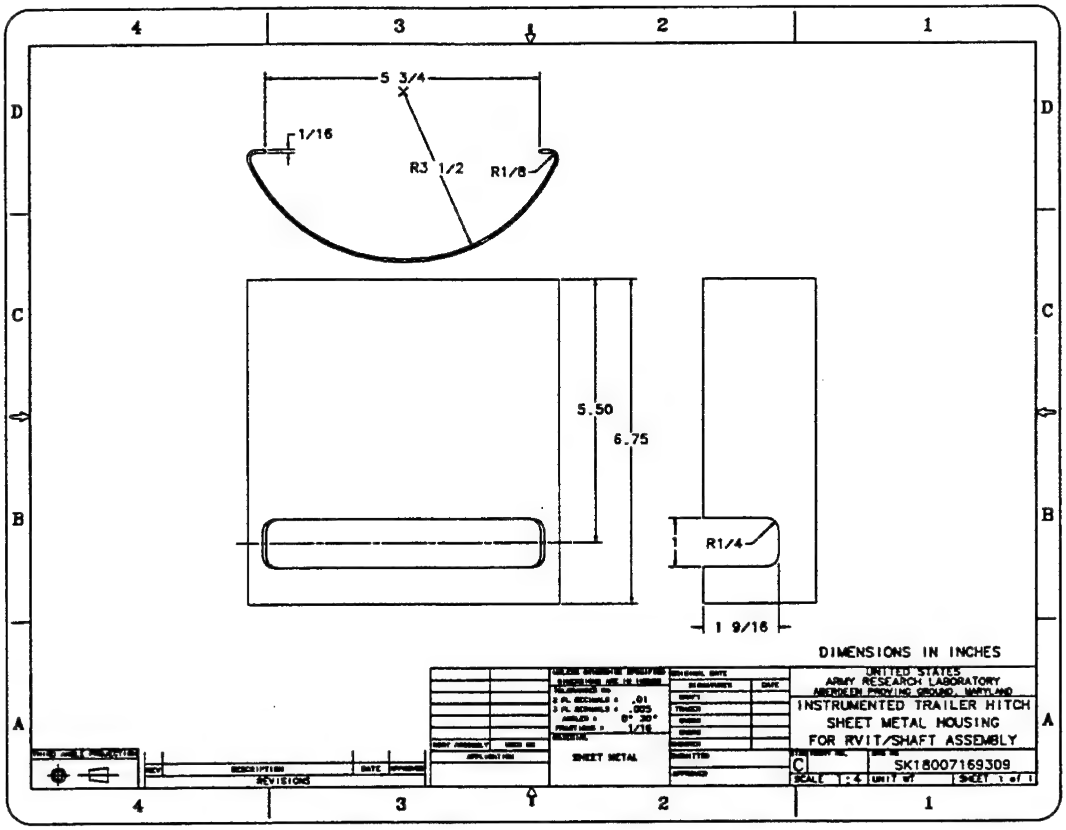


Figure A-4. Angle Measurement Bar and Guide.



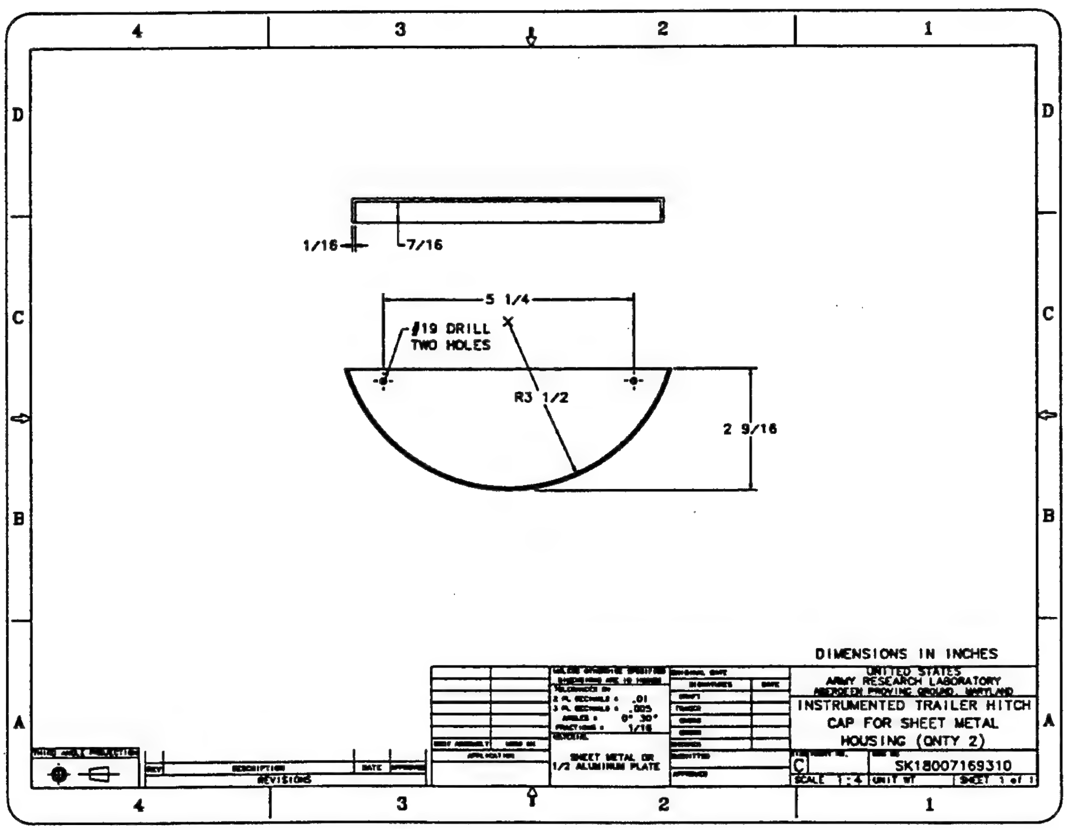
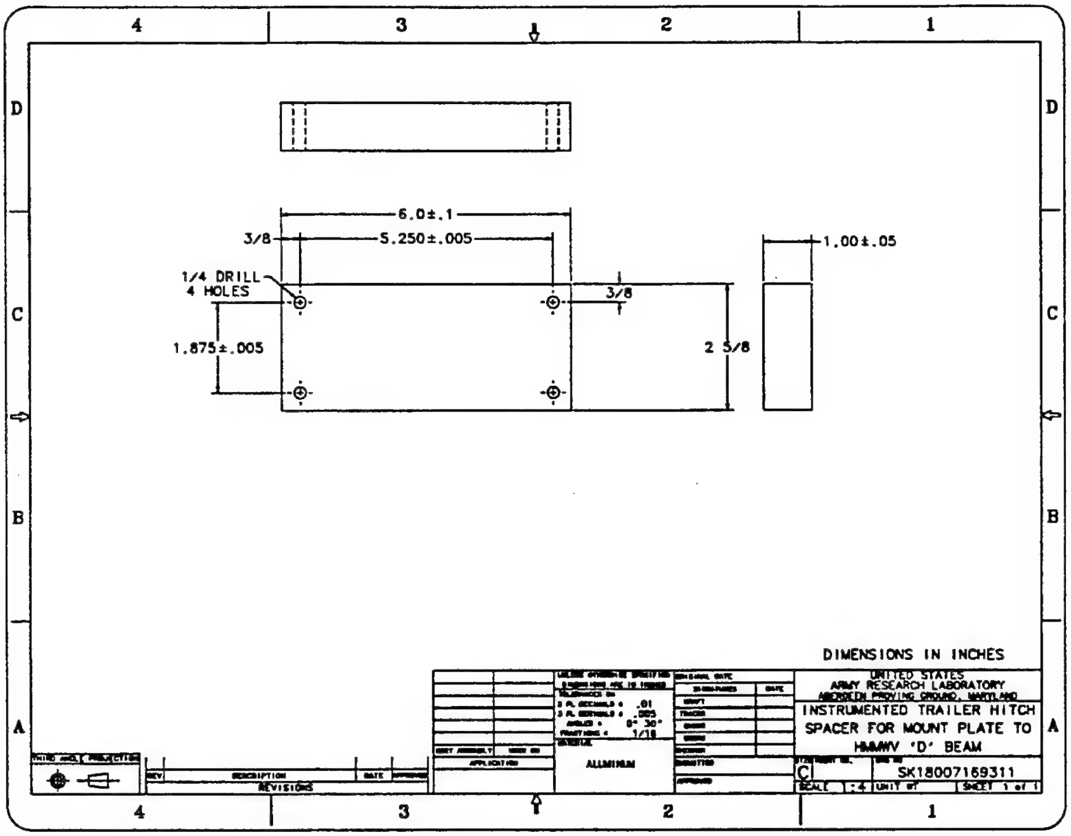


Figure A-5. Housing and Cap.



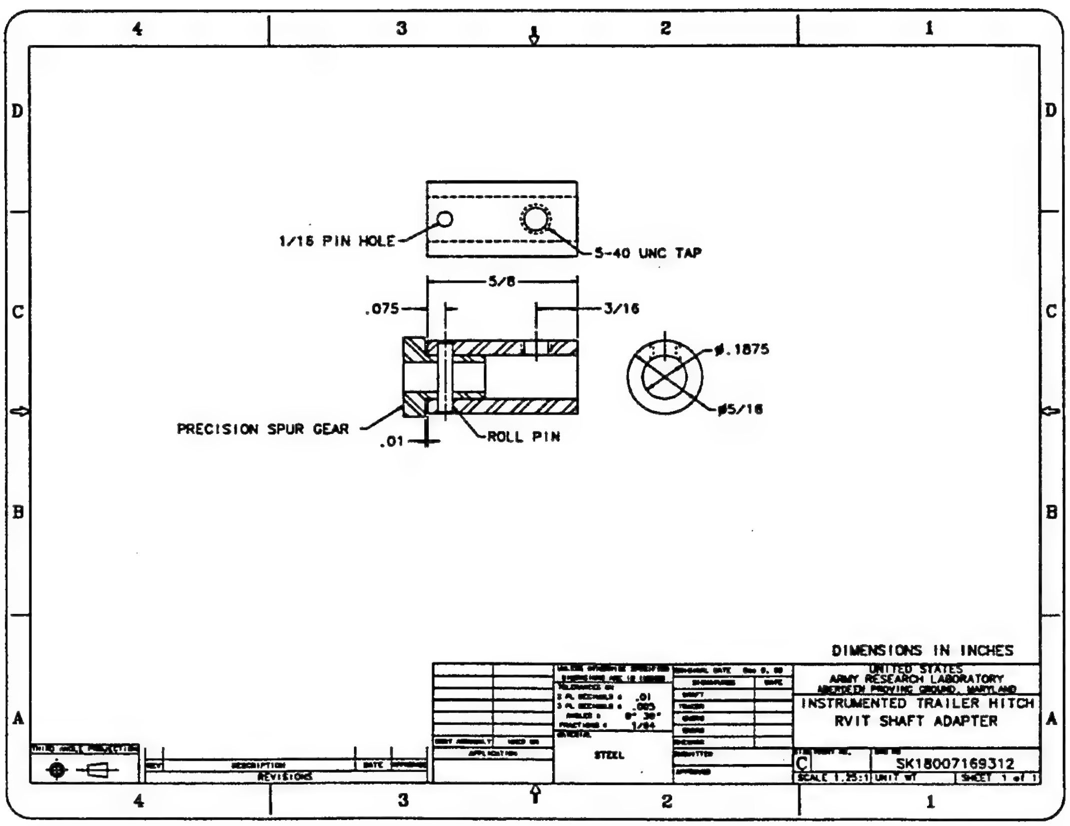


Figure A-6. Spacer and Shaft Adapter.

Appendix B:

Rotary Variable Inductance Transducer (RVIT) Specifications

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The wiring configuration is as follows.

RED . . . . Input Voltage.

BLACK . . . . Common.

WHITE . . . . Output Voltage.

To wire a rotary variable inductance tranducer (RVIT)-15-60, connect +5-V regulated input supply to RED and power supply common to BLACK. Output voltage, measured on WHITE (with respect to BLACK), will vary −3 V to +3 V as the shaft is rotated clockwise from −60° to +60° about the null position.

Table B-1. Performance Specifications for the RVIT-15-60 Series Rotary Position Sensor Single-Voltage Power Supply*

Angular Factor	−60° to +60°
Input Voltage (±5%)	+5 V
Output Voltage (±5%)	−3 V to +3 V
Input Current	25 mA (nominal)
Output Current	5 mA (maximum)
Output Impedance	1 Ω (maximum)
Frequency Response (−3 dB)	25 Hz (typical)
Nonlinearity	<0.25% fo full-scale output
Nonrepeatability and Hysteresis	<0.01% of full-scale output
Temperature Coefficient	<±0.02% of full-scale output/°F
Operating Temperature Range	0° C to +70° C
Storage Temperature Range	−55° C to +125° C
Maximum Shaft Load—Radial	44.5 N
Maximum Shaft Load—Axial	44.5 N
Weight	70 g

* Schaevitz Engineering, Pennsauken, NJ.

Table B-2. RVIT Calibration RVIT-15-60

Measured (°)	Measured (V Direct Current [DC])	Calculated (V DC)	Deviation (V DC)
60.00	+3.0282	+3.0319	-0.0037
55.00	+2.7797	+2.7787	+0.0010
50.00	+2.5284	+2.5254	+0.0030
45.00	+2.2756	+2.2722	+0.0034
40.00	+2.0226	+2.0190	+0.0036
35.00	+1.7681	+1.7658	+0.0023
30.00	+1.5132	+1.5126	+0.0006
25.00	+1.2589	+1.2593	-0.0004
20.00	+1.0030	+1.0061	-0.0031
15.00	+0.7495	+0.7529	-0.0034
10.00	+0.4968	+0.4997	-0.0029
5.00	+0.2443	+0.2465	-0.0022
-5.00	-0.2618	-0.2602	-0.0016
-10.00	-0.5147	-0.5134	-0.0013
-15.00	-0.7675	-0.7666	-0.0009
-20.00	-1.0203	-1.0198	-0.0005
-25.00	-1.2730	-1.2730	+0.0000
-30.00	-1.5262	-1.5263	+0.0001
-35.00	-1.7796	-1.7795	-0.0001
-40.00	-2.0324	-2.0327	+0.0003
-45.00	-2.2854	-2.2859	+0.0005
-50.00	-2.5384	-2.5391	+0.0007
-55.00	-2.7912	-2.7924	+0.0012
-60.00	-3.0422	-3.0456	+0.0034

NOTES: S/N = 1066, date = 09/03/93, range = ±60°, scale factor = 0.05069 V DC/°, null (actual) = -0.00006 V DC, linearity = 0.07% (least-squares calculation).

Appendix C:

Gear Head Specifications

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Table C-1. Gear Head Specifications

Description: tranducer gear head, bu-ord size, zero backlash, Sterling Instrument catalogue no. S9111A-T642A03S Manufacturer: Sterling Instrument, division of Designatronics Inc., New Hyde Park, NY	
Maximum Backlash	<1 arc min
Maximum Operating Torque	20 oz-in minimum
Total Transmission Error	12 arc minutes maximum
Integrated Transmission Error	12 arc minutes maximum
Housing Material	aluminum alloy 2024-T4
Housing Finish	black anodized
Gears and Shaft Material	stainless steel 416
Gears and Shaft Finish	passivated
Bearings	precision ball
Description: precision bellows coupling, pin type, zero backlash, Sterling Instrument catalogue no. S9901Z-G404-24	
Bellows Material	phos. bronze, brass pins
Angular Misalignment	5° maximum
Maximum Speed	2,000 rpm

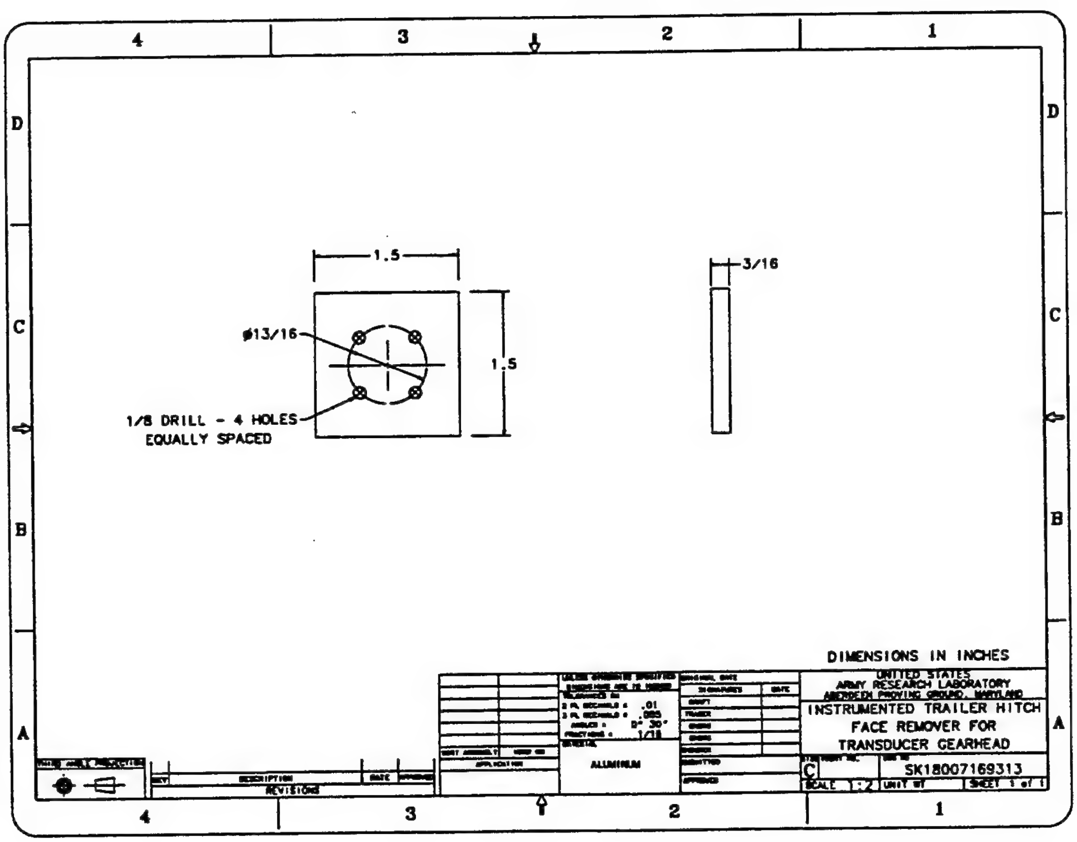

Figure C-1. Gear Head Face Remover Tool.

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13. ABSTRACT *(Maximum 200 words)*

As part of a project to demonstrate that an unmanned ground vehicle (UGV) could remotely back up with a trailer, a simple proof-of-concept device was designed to measure the angle between a high-mobility multipurpose wheeled vehicle (HMMWV) pintle hook and a trailer tow bar. A suitable algorithm could compute the UGV steering angle required for a trailer to follow a given reverse path and would be a function of the angle between the UGV and the trailer. This report gives the details of a design for a hitch angle measurement device (HAMD) to be used as input to a steering transfer function. Derivation of the transfer function is not included.

14. SUBJECT TERMS

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